JSACE 4/21

The Environmental Performances of Reclaimed Asphalt and Bituminous Sand Pavements for Transition Towards Low Carbon Sustainable Road Infrastructure

Received 2017/10/09

Accepted after revision 2017/12/18

# The Environmental Performances of Reclaimed Asphalt and Bituminous Sand Pavements for Transition Towards Low Carbon Sustainable Road Infrastructure

**Mihaela Condurat***

Regional Directorate of Roads and Bridges Iasi (D.R.D.P. Iasi), Romanian National Company of Road Infrastructure Management (C.N.A.I.R. S.A Romania), Gh. Asachi Street, Iasi, 700481, Romania

**Gabriela Ionita**

Department of Transportation Infrastructure and Foundations, Faculty of Civil Engineering and Building Services, Gheorghe Asachi" Technical University of Iasi, 43, Dimitrie Mangeron Blvd., Iasi 700050, Romania

*Corresponding author: **conduratmihaela@yahoo.com**

http://dx.doi.org/10.5755/j01.sace.21.4.18486

Given the climate change, the high levels of pollution and the depletion of natural resources, the adoption of low carbon practises for road infrastructure improvement with regards to energy consumption is essential for a sustainable future. These practises, including the incorporation of nonconventional materials, such as oil sands or bituminous sands in pavement construction and the recycling of the existing deteriorated pavements, represent significant methods which can be performed for a better conservation of resources, and therefore the protection of the environment. In terms of environmental indicators assessment, the results of recent research undertaken for road pavement reinforcement strategies are presented. The Global Warming Potential expressed as quantities of $CO_2$e emissions for a road pavement incorporating various alternative materials, such as oil sand and reclaimed asphalt has been evaluated using a life cycle assessment (LCA) study performed with asPECT software. The results obtained from these studies are presented within this paper and specific recommendations with regards to various employed approaches are given. These are required for minimizing the environmental impact of transport infrastructure. The paper aims to highlight the need for effective measures concerning road pavements maintenance and intervention works. These measures are intended to extend the pavements lifecycle and therefore to reduce the overall ecological impact associated with the reconstruction of the road pavement because this action is correlated with significant quantities of polluting emissions released into the atmosphere, enormous granular materials and energy consumption and thus, an exponential increase of the greenhouse effect.

**Keywords:** bituminous sand, environmental impact, life-cycle assessment, reclaimed asphalt pavement, road pavement.

Journal of Sustainable Architecture and Civil Engineering
Vol. 4 / No. 21 / 2017
pp. 50-62
DOI 10.5755/j01.sace.21.4.18486

## Introduction

### General concepts of low carbon practices associated with road pavements

Defining low carbon mobility can be achieved by taking into account specific actions related to the transport system which leads to significantly reduced consumption of non-renewable resources and smaller quantities of greenhouse gas emissions released into the atmosphere (Condurat and Patterson, 2016).

In terms of new technologies and processes supporting the transition towards low carbon mobility, as a consequence of the alarming increase in pollution levels worldwide during the last years, the need to promote alternative road construction methods has emerged. The progressive increase in the demand for asphalt mixtures and therefore for road bitumen, correlated with material quantitative and qualitative deficiencies have emphasized the importance of nonconventional components in the asphalt mixes, such as bituminous sand and reclaimed asphalt pavements.

Thus, the paper will emphasize the new developments related to transport infrastructure towards low carbon mobility represented in our case by the incorporation in pavement construction of nonconventional materials, such as oil sands or bituminous sands and recycling techniques of the existing deteriorated pavements within the process of rehabilitation of the road network.

Given that the rehabilitation possibilities are limited due to high costs and the fact that the bituminous binder at this stage is imported, oil sand is an effective alternative. Bituminous sand is a local material, specific only to certain areas of the world, which have the advantage of containing in their natural state, a percentage of natural bitumen. Using oil sands is imposed by the continuously increasing price for bituminous binders, along with the gradual degradation of Romanian road network, in connection with the increase of fleet vehicle composition.

Low carbon road infrastructure improvement practises, including incorporation of waste and recycling materials in pavement construction and recycling techniques of the existing deteriorated pavements represent significant methods which can be performed for a better conservation of resources, while being environmental friendly. The long term positive results, correlated with the recycling process, include the reduction of the natural resources depletion and thus a reduction of environmental impacts of the road pavement, decrease of materials consumption, energy usage, construction waste and associated costs (Al-Qadi, Sayed, Alnuaimi, and Masad, 2008; Al-Rousan, Asi, Al-Hattamleh, and Al-Qabla, 2008).

### The use of oil sands in the road pavement construction sector

Incorporating alternative materials in road pavements comes with great benefit to the society. In order to minimize the dependency on the petroleum-based asphalt, bituminous sand can be easily used.

The aim of this paper is to emphasize the ecological benefits related with an asphalt pavement mix designed with a percentage of oil sand incorporated into the mix, which has previously been tested in a road laboratory and it has proven to fulfil the physical and mechanical characteristics of road pavements (Ioniță and Gugiuman, 2016).

Bituminous binders are complex mixtures of animal origin hydrocarbons or are obtained through a pyrogenic reaction, often together with their combinations with oxygen, nitrogen, sulphur, etc. Bituminous sands are found in liquid, viscous or solid form, having a dark brownish and black colour and are completely soluble in carbon disulfide (Matasaru, Craus, and Dorobantu, 1966; Ioniță and Gugiuman, 2016).

Oil sands are sand deposits impregnated with a thick, viscous material called bitumen (Speight, 2009). These are mixtures composed of quartz sand and fine particles, thin water cover and bitumen that fill the pore spaces between the sand granules (Probstein and Hicks, 2006). Major bituminous sand deposits are found around the world; yet, the largest deposits are located in North America and Eurasia. The largest bituminous sand field is found near Athabasca, Alberta Canada, but there are significant oil reserves located in Venezuela (Lake Bermudes), Syria, Cuba, Madagascar, Albania (SELENE) (Anochie-Boateng and Tutumluer, 2012).

In the "*Economic Feasibility of Oil Sand Use in Asphalt Pavements*", a comparative economic analysis of these two alternatives is performed and the conclusion drawn was "An overall favorable economic result for private industry, as well as, both local and state governments is predicted" (Gwilliam, 2010). Another benefit of bituminous sand road pavements is the reduced mixing temperature. The mixing temperature for classical hot asphalt mix is about 177° C compared to 104°C which is the optimum mixing temperature for bituminous sand mixes (Vrtis, 2013). As it can be seen, there is a substantial reduction in the mixing temperature for the second alternative, which can be translated into a more environmentally friendly pavement by reducing the emissions produced by these processes latter.

In Romania, oil sands are located in two geographical zones, as follows: Bihor County, at Derna - Tatarus - Budoi site and Prahova County, at Matita and Pacuret site. These bituminous sands have an average of 10 to 20% pure bitumen in their structure and therefore can be used for road works. Depending on the road works for which these bituminous sands are used, the bituminous mixtures can be designed only with bituminous sand or bituminous sand and additional hard paving grade bitumen (Ionita and Gugiuman, 2016). The technological process of extraction is surface mining due to the fact that the oil sand deposits are at a shallow depth below the thin layer of soil.

### Reclaimed asphalt pavement

When distresses appear in the road pavement affecting the structural integrity of the road and the operational status of the surface, in order to meet the criteria for reducing GHG emissions and using smaller amounts of materials, pavement recycling is an essential process. The technological process of recycling asphalt mixtures consists in the usage of material derived by milling, grinding and mixing these with correspondent amounts of binder and natural aggregates. The material obtained is then properly bedded and compacted. The asphalt course obtained using this procedure must meet the quality requirements of new asphalt mixtures, namely workability, compaction, mechanical stability and insensitivity to water (Florescu, 2010).

The dosages of materials incorporated in recycled mixtures are established through laboratory studies for asphalt pavements design, the dosage of embedded Reclaimed Asphalt Pavement (RAP) varying between 20% (Europe) and 70% (USA) (FHWA, 2011). Transport Research Laboratory (TRL) has been conducted studies upon recycled materials in order to determine the viability and the behaviour of mixtures that have different quantities of asphalt waste (up to 30%) and polymer modified bitumen. Thus, an amount of 10% recycled asphalt (RA) material can be incorporated into the mixes without previously processing the reclaimed material. The proportion of RA can increase up to 50%, if the homogeneity of the RA is controlled. In this case, the effect of residual binder in the RA on the active binder is also to be taken into consideration (Al-Qadi, Sayed, Alnuaimi, and Masad, 2008).

In Romania, the recycling of flexible asphalt pavements is not current practice, despite the need, the economic, environmental and social benefits and the physical and mechanical characteristics similar to those of new materials. Usually, the RAP is stored in landfills, used for the execution of the binder course for low road category or as filler material. Thus, the impact associated with the use of RAP, expressed in terms of pollutant emissions, has been further analysed in this paper, not only taking into consideration the actual practice (as additional material in the binder course), but also within all bituminous layers.

## Methods

### The Life Cycle Assessment Analysis

Life Cycle Assessment (LCA) enables the definition of the potential environmental impact assessment associated with the product throughout its lifetime (using non-renewable resources, health, ecological consequences, etc.) in order to increase resource efficiency and to remove its quality issues (Treweek, 2009). The LCA is realized according with international standards ISO 14040 and ISO 14044. The LCA method enables the identification of opportunities for improving the environmental aspects at various times in their life cycle and the selection of performance indicators and measurement techniques, and is considered a practical instrument in the decision making processes. A Life Cycle Assessment Analysis of a system product is performed stepwise as shown in Fig. 1. Based on a LCA analysis, series of indicators can be quantified, the most representative being the Global Warming Potential (GWP). This indicator represents the contribution of carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) to the exacerbation of global warming. Though, the carbon dioxide has the highest contribution to the global warming effect. Taking into consideration the importance of this indicator, specific analyses for the evaluations of the ecological effect of a road pavement reinforcement will be further presented, expressed in terms of $CO_2$e emissions.

The options for defining the boundaries are represented by CRADLE TO GRAVE, CRADLE TO GATE, GATE TO GRAVE and GATE TO GATE (Curran, 2012).

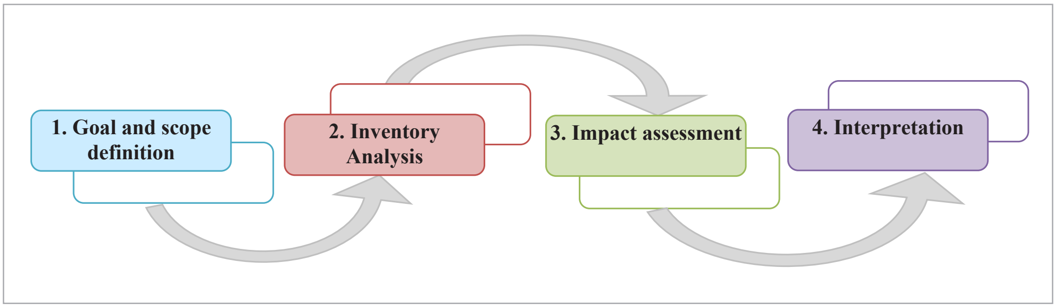



Fig. 1

Steps in performing a Life Cycle Assessment (ISO, 1997)

Furthermore, the paper will present the influence of various reinforcement strategies for asphalt road pavements through a Life Cycle Assessment analysis conducted according to the methodology incorporated into the asPECT software, version 3.1., in a „cradle-to-grave" perspective in order to only determine the Global Warming Potential correlated with these strategies.

**asPECT software methodology**

The asPECT software, Version 3.1 has been developed by TRL and provides a new methodology to determine the pollutant emissions released into the atmosphere during the pavement life cycle due to asphalt materials used on road constructions. This software allows the assessment of carbon dioxide emissions on the basis of collected information regarding materials, transport and mixture plant characteristics (TRL, 2014). The software enables calculation of $CO_2$e emissions related with the production, laying and maintenance of road layers by considering all the stages of materials and energy production and all the processes from raw material extraction, production, transport and use phase of the asphalt mixes to the end of their life (Cradle to Grave), shown in Fig. 2. $CO_2$e or carbon dioxide equivalent is an abbreviation which expresses the effect of each various greenhouse gas regarding the amount of $CO_2$ that would produce the same amount of global warming (EPA, 2009).

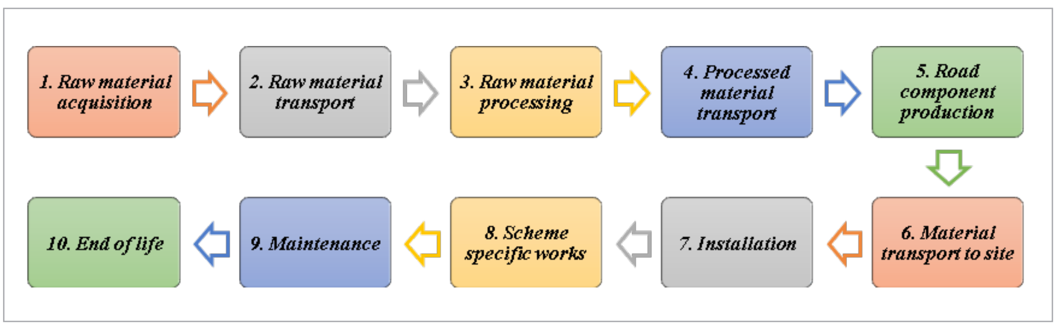



Fig. 2

The life cycle stages of asphalt mixtures Cradle to Grave (TRL, 2014)

According specialized literature (TRL, 2014), the process for calculating the $CO_2$e emissions associated to bituminous road pavement consists of three main stages, namely:

A. The introduction of raw materials used in the asphalt mixture (total annual energy consumption for the acquisition, broken down by type of fuel and operation);
B. Data introduction regarding the asphalt mixes plant characteristics (plant type, annual production, energy consumption and asphalt mix composition);
C. Data introduction regarding installation of bituminous mix and visualization of the results.

## Case Study – Life Cycle Assessment of Reinforced Road Pavements Using Various Alternative Materials

In order to improve road infrastructure and to promote and stimulate alternative materials and technologies usage in road construction, in the past years, various studies regarding the incorporation of bituminous sand from several Romanian sites into asphalt mixes, as well as reclaimed asphalt materials have been initiated and tested in the frame of "Gheorghe Asachi" Technical University of Iasi at an extensive scale. The studies required as a response to the actual environmental and energetic challenges, involves the reinforcement of a road pavement for light traffic using different engineering approaches. Road pavements for light traffic are usually carried out from coated materials and bitumen macadam, applied in a singular layer over the existing gravelling. The service life of road pavements for light traffic is about 8 to 12 years. The disadvantages associated with bituminous sand pavements are the following:

- the high bitumen variation in the content of bituminous sands,
- the technical qualities of the sand,
- the impossibility of a perfect control of the technological process, *this type of a material cannot be used for roads with intense and heavy traffic*.

However, oil sands present positive technical behaviour when used for reinforcing the asphalt road pavements for light traffic.

Reinforcement works are being performed in order to total or partial compensate the physical wear due to normal operation or environmental agents actions, upgrading the technical characteristics imposed by an increased road traffic, replacement of elements, parts of construction that are out of use, all of which affect the resistance, stability, safety in operation and environmental protection. The reinforcement works are usually carried out through two asphalt courses, laid on the existing road pavement.

**Methods for the Case Study**

Considering the elevated levels of pollution recorded during the last years and the European Commission studies, the development of alternative road construction technologies and processes is required. Moreover, besides the initial construction process of the road pavement, the periodical maintenance and reinforcement strategies to be applied represent significant factors for reducing the carbon footprint and, also, in increasing the service life time of the road. Further, a more significant key role in decreasing polluting emissions is represented by the time of intervention. If the reinforcement strategy is applied at the optimum moment in the road service life, the costs and the raw materials and energy consumption will be considerably reduced and the lifetime of the road will be enlarged. Otherwise, if the road is not reinforced when needed, the distresses progress exponentially, leading to the inability to use the road on full safety and comfort conditions. Additionally, the rehabilitation investments, seen both in a financial perspective, as well as in terms of material consumption and labour required, will be directly correlated with the worsening of greenhouse effect.

The paper shows the final results of recent research undertaken associated with the quantitative assessment of carbon dioxide equivalent emissions and energy consumption correlated with various reinforcement strategies for road pavements for light traffic using the asPECT software.

The research based on environmental criteria of transport infrastructure has been performed using a **Life Cycle Assessment Analysis (LCAA)**. The Case Study deals specifically with road pavement reinforcement strategies taking into consideration various nonconventional materials. The Life Cycle Assessment Analysis has been conducted on the entire built section of 1000 ml long and 7.0 m wide using a **CRADLE TO GRAVE** option, presented in Fig. 2. The Global Warming Potential, expressed in terms of $CO_2$e emissions has been assessed using the asPECT software, version 3.1. The Case Study was conducted taking into consideration six constructive alternatives, presented in Fig. 3, for the reinforced road infrastructures for light traffic, as follows:

According **Alternative 1**, the reinforced road pavement is composed of the asphalt concrete with the maximum size of the aggregate of 16 mm (BA 16) for the wearing course, laid on an asphalt concrete with the maximum size of the aggregate of 25 mm (BAD 25) for the binder course, supported by the asphalt base (AB2), constructed over the existing structure.

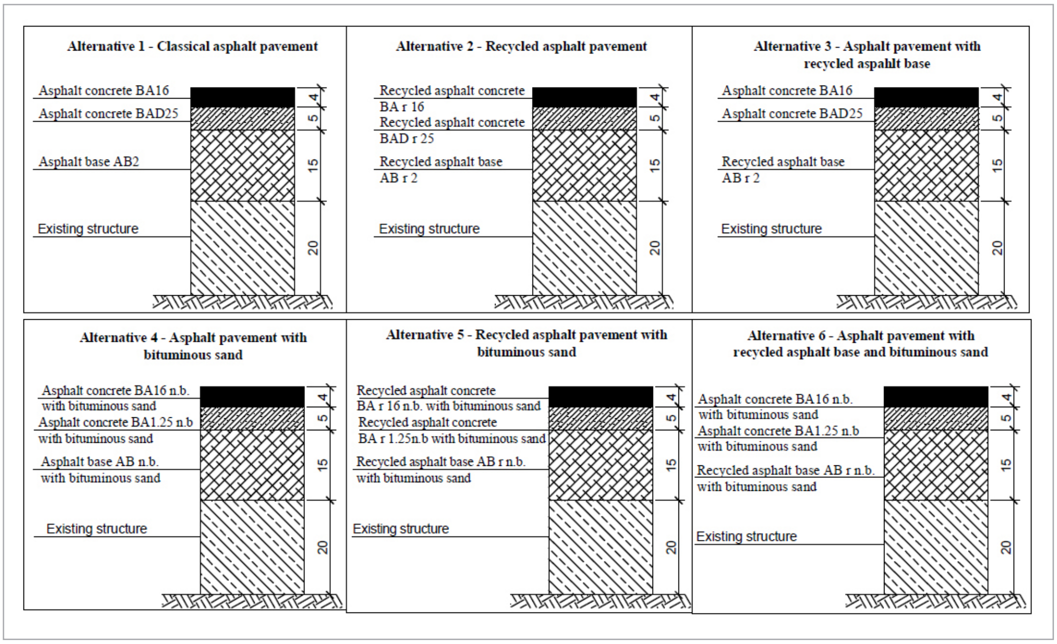



Fig. 3

Alternatives for the Reinforced road pavements

According **Alternative 2**, the reinforced road pavement is composed of the recycled asphalt concrete with the maximum size of the aggregate of 16 mm (BAr 16) for the surface layer, laid on a recycled asphalt concrete with the maximum size of the aggregate of 25 mm (BADr 25) for the binder course, supported by a recycled asphalt base (ABr).

**Alternative 3** refers to a reinforced road pavement composed of an asphalt concrete course, laid on an asphalt concrete binder course, supported by a recycled asphalt base. This is the common practice in Romania at this stage, but there are studies undergoing for the implementation of recycling materials in all the road pavement layers.

For the **Alternative 4**, the reinforced road pavement is composed of the asphalt concrete with bituminous sand incorporated into the mix (BA 16 n.b.) for the wearing course, laid on an asphalt concrete with bituminous sand (BA 1 25 n.b.) for the binder course, supported by the asphalt base also designed with bituminous sand (AB n.b.).

For the **Alternative 5**, the reinforced road pavement is composed of the recycled asphalt concrete having bituminous sand incorporated into the mix (BAr 16 n.b.) for the surface layer, laid on a recycled asphalt concrete with bituminous sand (BAr 1 25 n.b.) for the binder course, supported by a recycled asphalt base with bituminous sand (ABr n.b.).

For the **Alternative 6**, refers to a reinforced road pavement composed of an asphalt concrete course with bituminous sand, laid on an asphalt concrete binder course with bituminous sand, supported by a recycled asphalt base also with bituminous sand into their composition.

## Results and discussions

**Alternative 1:**

Project results summary for Alternative 1 are presented below, in Table 1.

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2e$ |
|---|---|---|---|
| 1-3 | Material extraction and processing | 52,88 | 203.405,60 |
| 4 | Transport to plant | 36,52 | 140.481,67 |
| 5 | Asphalt production | 199,99 | 769.258,85 |
| 6 | Transport to site | 30,17 | 116.052,11 |
| 7 | Laying and compacting | 4,70 | 18.078,55 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.536,55 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. CO2e | 1.247.276,78 | 1.316.953,33 | 1.316.953,33 |
| tonnes | | 3996,50 | 3996,50 |
| Kg CO2e/tonne | 324,26 | 329,53 | |

Table 1

$CO_2e$ emissions correlated with Alternative 1 for road pavement reinforcement

Alternative 1 considers a classical road pavement, as a reinforcement solution. The road pavement is composed by three asphalt courses with different technical characteristics. From an ecological perspective, this solution is highly polluting. The energy and raw material consumption are the greatest from all the others studied alternatives. The main reason is derived from the fact that this construction option requires only virgin aggregates and the amount of bitumen used is between normal values (4.5 % - 6.5%), while in the other alternatives this percentage is reduced. The total quantity of $CO_2e$ associated with the classical road reinforcement alternative, in a Cradle to Grave perspective is **1.316.953,33 kg**. Thus, in order to move towards low carbon road infrastructure, more eco efficient strategies have been further assessed.

**Alternative 2:**

Project results summary for Alternative 2 are presented in Table 2.

In order to comply with the low carbon road infrastructure principles, the recycling road pavement process has become more and more important. Hence, a reinforcement road pavement alternative, carried out with reclaimed asphalt pavement incorporated into the mix has been designed and analyzed in terms of ecological impact during their life cycle. As it can be observed from the Table 2, the results obtained for this alternative are significantly smaller compared with the classical road pavement, with only a **271,25** kg $CO_2$/t from a Cradle to Grave perspective. This study emphasizes the need to adopt greener ways to construct the transport infrastructure by reusing the existing material laid previously in combination with smaller quantities of virgin aggregates. Also, the fact that the reclaimed asphalt pavement already has an amount of bitumen in their composition; a reduced quantity of the bituminous binder can be used, which translates into a reduction of the carbon footprint associated with this strategy.

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2$e |
|---|---|---|---|
| 1-3 | Material extraction and processing | 20,89 | 80.371,19 |
| 4 | Transport to plant | 22,03 | 84.752,61 |
| 5 | Asphalt production | 185,91 | 715.119,14 |
| 6 | Transport to site | 30,17 | 116.052,11 |
| 7 | Laying and compacting | 4,70 | 18.078,55 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.536,55 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. $CO_2$e | 1.014.373,61 | 1.084.050,16 | 1.084.050,16 |
| tonnes | 3996,50 | | |
| Kg $CO_2$e/tonne | 263,71 | 271,25 | |

Table 2

$CO_2$e emissions correlated with Alternative 2 for road pavement reinforcement

### Alternative 3

Project results summary for Alternative 3 are presented below, in **Table 3**.

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2$e |
|---|---|---|---|
| 1-3 | Material extraction and processing | 23,71 | 91.206,62 |
| 4 | Transport to plant | 25,86 | 99.478,14 |
| 5 | Asphalt production | 191,73 | 737.484,41 |
| 6 | Transport to site | 30,17 | 116.052,11 |
| 7 | Laying and compacting | 4,70 | 18.078,55 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.536,55 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. $CO_2$e | 1.062.299,83 | 1.131.976,38 | 1.131.976,38 |
| tonnes | 3996,50 | | |
| Kg $CO_2$e/tonne | 276,17 | 283,24 | |

Table 3

$CO_2$e emissions correlated with Alternative 3 for road pavement reinforcement

In this alternative, it has been considered only the base course carried out with reclaimed asphalt pavement. This is the usual procedure in Romania despite the good behaviour and the physical and mechanical characteristics of the RAP materials. Although this alternative shows positive outcome in terms of environmental impact, in order to move towards low carbon road infrastructure, further steps have to be taken, namely entire road asphalt pavement recycling and incorporating other unconventional materials.

**Alternative 4**

Project results summary for Alternative 4 are presented below, in **Table 4**.

Table 4

$CO_2$e emissions correlated with Alternative 4 for road pavement reinforcement

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2$e |
|---|---|---|---|
| 1-3 | Material extraction and processing | 5,30 | 20.484,06 |
| 4 | Transport to plant | 23,29 | 90.075,92 |
| 5 | Asphalt production | 173,49 | 670.848,68 |
| 6 | Transport to site | 30,17 | 116.664,58 |
| 7 | Laying and compacting | 4,70 | 18.173,96 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.875,56 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. $CO_2$e | 916.247,20 | 986.262,76 | 986.262,76 |
| tonnes | 4016,80 | | |
| Kg $CO_2$e/tonne | 236,95 | 245,53 | |

Alternative 4 presents a reinforced road pavement carried out by incorporating an amount of bituminous sand extracted from Derna Tatarusi site, which contains 20% natural bitumen in their composition. Hence, the amount of bituminous binder in the asphalt mix decreases significantly. This reduction is directly correlated with the quantity of carbon dioxide emissions released into the air. Also, the fact that the oil sand does not need complicated excavation methods and technologies, given the close proximity to the top soil, emphasize the eco-efficiency of this alternative.

**Alternative 5**

Project results summary for Alternative 5 are presented below, in **Table 5**.

Table 5

$CO_2$e emissions correlated with Alternative 5 for road pavement reinforcement

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2$e |
|---|---|---|---|
| 1-3 | Material extraction and processing | 4,59 | 17.766,64 |
| 4 | Transport to plant | 14,30 | 55.286,78 |
| 5 | Asphalt production | 175,91 | 680.190,67 |
| 6 | Transport to site | 30,17 | 116.664,58 |
| 7 | Laying and compacting | 4,70 | 18.173,96 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.875,56 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. $CO_2$e | 888.082,63 | 958.098,19 | 958.098,19 |
| tonnes | 4016,80 | | |
| Kg $CO_2$e/tonne | 229,67 | 238,52 | |

Based on the results obtained from the alternatives studied above, one can notice the ecological advantage of incorporating into the mix of reclaimed asphalt pavement material or bituminous sand. However, as Table 4 shows, blending these two procedures, have the most positive ecological outcomes. The total quantity of $CO_2e$ from Cradle to Gate is **958.098,19** kg, almost with **27.25% smaller than the classical reinforcement solution**. The ecological benefits derived from these results are significant, given the scale of road constructions. Fig. 4 presents the emissions segmentations based on the life cycle stage. As it can be seen below, the biggest proportion of

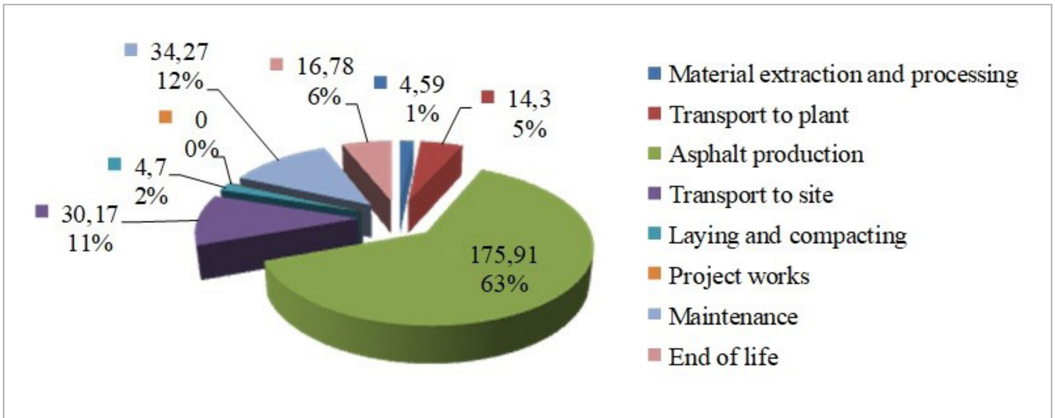



Fig. 4

Global Warming Potential expressed in terms of kg $CO_2e$/t associated with the most eco efficient reinforcement strategy

pollutant emissions comes from the asphalt production. A big part in the emissions reduction is played by the temperatures required for the asphalt mixes with oil sand and RAP, significantly lower compared with a typical solution. Also, the emissions associated with the transport to the plant and material extractions and processing phases are smaller, as a direct consequence of the unconventional materials added.

**Alternative 6**

Project results summary for Alternative 6 are presented below, in Table 6.

Table 6

$CO_2e$ emissions correlated with Alternative 6 for road pavement reinforcement

| STEP | LIFE CYCLE STAGE | kg $CO_2$/t | TOTAL kg $CO_2e$ |
|---|---|---|---|
| 1-3 | Material extraction and processing | 4,69 | 18.124,32 |
| 4 | Transport to plant | 16,66 | 64.410,40 |
| 5 | Asphalt production | 174,96 | 676.546,22 |
| 6 | Transport to site | 30,17 | 116.664,58 |
| 7 | Laying and compacting | 4,70 | 18.173,96 |
| 8 | Project works | 0,00 | 0,00 |
| 9 | Maintenance | 34,27 | 5.140,00 |
| 10 | End of life | 16,78 | 64.875,56 |

| | Steps 1 to 7 | Asphalt | Project |
|---|---|---|---|
| Total kg. $CO_2e$ | 893.919,47 | 963.935,03 | 963.935,03 |
| tonnes | | 4016,80 | |
| Kg $CO_2e$/tonne | 231,18 | 239,98 | |

Alternative 6, with bituminous sand, compared with the first three studied alternatives also presents positive effects on the environment, even if the reclaimed material is only added in the base course. As it can be observed the total quantity of $CO_2$e/tonne released into the atmosphere due to the execution of a reinforced road pavement using recycled asphalt base and bituminous sand within the bituminous mixes is equal with 239,98 kg. This is translated as well with ecological advantages compared with the classical ones.

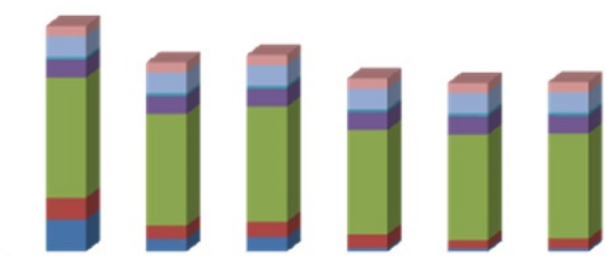
The Global Warming Potential, expressed in terms of $CO_2$e emissions has been assessed using the asPECT software, developed by TRL Laboratory form UK. The results, broken down accordingly with the life cycle stages for the six alternatives considered are presented in Table 7.

Table 7

Summary of $CO_2$e emissions associated with the alternatives for the reinforced road pavements

| No. | Life cycle stage | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 | Alternative 5 | Alternative 6 |
|---|---|---|---|---|---|---|---|
| | | kg $CO_2$e/t | kg $CO_2$e/t | kg $CO_2$e/t | kg $CO_2$e/t | kg $CO_2$e/t | kg $CO_2$e/t |
| TOTAL kg $CO_2$e from CRADLE TO SITE $CO_2$e/t | | 1.247.276,78<br>324,26 | 1.014.373,61<br>263,71 | 1.062.299,8<br>276,17 | 916.247,20<br>236,95 | 888.082,63<br>229,67 | 893.919,47<br>231,18 |

As it can be noticed from the chart above (Fig. 5), the greatest proportion of $CO_2$e corresponds to the production of asphalt mixture due to the high energy consumption required for heating and drying the aggregates, mixing the components and other additional process from the plant. However, from the plant point of view, these emissions quantities can significantly decrease if one uses bituminous sand in the asphalt mix, mostly due to the low temperatures required into the technological process and the fact that these asphalt mixtures are carried out with smaller quantities of bitumen, material which, according recent studies (TRL, 2014) has about 190,00 kg $CO_2$e/t. Furthermore, the pollutant emissions associated with the material extraction and processing life cycle stage is reduced in the case of the oil sand, because this material is found at a shallow depth below the soil in Romania. Thus the technological processes are minimal. Also, the extraction procedure is represented by surface mining or open pit. As expected, the most eco efficient reinforcement strategy for road pavement designed for light traffic is represented by Alternative 5, which combines the use of both unconventional materials in the asphalt courses, the total $CO_2$e reaching



| | A 1 | A 2 | A 3 | A 4 | A 5 | A 6 |
|---|---|---|---|---|---|---|
| End of life | 16,78 | 16,78 | 16,78 | 16,78 | 16,78 | 16,78 |
| Maintenance | 34,27 | 34,27 | 34,27 | 34,27 | 34,27 | 34,27 |
| Project works | 0 | 0 | 0 | 0 | 0 | 0 |
| Laying and compacting | 4,7 | 4,7 | 4,7 | 4,7 | 4,7 | 4,7 |
| Transport to site | 30,17 | 30,17 | 30,17 | 30,17 | 30,17 | 30,17 |
| Asphalt production | 199,99 | 185,91 | 191,73 | 173,49 | 175,91 | 174,96 |
| Transport to plant | 36,52 | 22,03 | 25,86 | 23,29 | 14,3 | 16,66 |
| Material extraction and processing | 52,88 | 20,89 | 23,71 | 5,3 | 4,59 | 4,69 |

Fig. 5

$CO_2$e emissions associated with the alternatives for the reinforced road pavements expressed in terms of kg $CO_2$e /t for each of the life cycle stage of the reinforced road pavement

888.082,63 kg in a Cradle to Site perspective. This means that, compared with the most polluting alternative (A1 – classical reinforcement solution), the pollution decreases with almost 30%. In the same context the costs will also decrease as local and recycled materials are incorporated into the asphalt mixes. In conclusion, reinforcing the existing structure with unconventional materials shows positive impacts expressed in terms of environmental and economic effects through the use of small amounts of raw materials and energy required for extraction.

Furthermore, to decrease the ecological impact of road transport infrastructure, a significant factor is represented by the humidity of component materials, as the biggest amount of energy is consumed in drying and heating of aggregates. Also, another way to increase the efficiency of asphalt production processes implies the use of reclaimed asphalt mixtures and oil sand, when the material is available near the road sites, which results in considerable reductions of pollutant emissions.

## Conclusions

The aim of this paper is to emphasize the ecological benefits related with an asphalt pavement mix designed with a percentage of oil sand incorporated into the mix, which has previously been tested in a road laboratory and it has proven to fulfil the physical and mechanical characteristics of road pavements. Thus, considering that the most serious environmental issues facing mankind nowadays is represented by the global warming and climate change mostly due to high concentration of pollutants emitted into the air, the paper presents the results of recent research studies undertaken for the assessment of environmental indicators associated to road pavements reinforcement, based on a Cradle to Grave perspective, which involves all of the stages from raw material extraction, production, transportation and use phase of the products to their end of life. The environmental analyzes have been conducted on the entire built section of one-kilometre-long and 7,0 m wide using a CRADLE TO GRAVE option, contained in the asPECT software. The Life Cycle Assessment Analysis has been conducted on six reinforcement road alternatives for light traffic using various unconventional materials, namely oil sand or bituminous sand supplied from Derna Tatarusi site and reclaimed asphalt pavement, derived from milling and grinding the asphalt road surface.

One may notice that in order for bituminous sand road pavements to be used instead of conventional asphalt ones, these have to be advantageous in terms of costs, while still fulfilling the physical and mechanical characteristics. The economic and ecological advantages of bituminous sand road pavements decline as further the material has to be transported away from the site, due to transportation distance. Given that the sand is already mixed with the bituminous binder, in the case of oil sands, transportation costs decrease compared with the traditional asphalt mixes, where transporting the binder leads to additional costs.

As expected, the most eco efficient reinforcement strategy for road pavement designed for light traffic is represented by Alternative 5, which combines the use of both unconventional materials in the asphalt courses, the total $CO_2$e reaching 888.082,63 kg in a Cradle to Site perspective. This means that, compared with the most polluting alternative (A1 – classical reinforcement solution), the pollution decreases with almost 30%. In the same context the costs will also decrease as local and recycled materials are incorporated into the asphalt mixes. In conclusion, reinforcing the existing structure with unconventional materials shows positive impacts expressed in terms of environmental and economic effects through the use of small amounts of raw materials and energy required for extraction.

However, a close attention should be given for the asphalt mixtures temperatures and the technological process in order for these pavements to efficiently perform under traffic. The main disadvantage associated with the use of these unconventional materials is the fact that, for now, it cannot be used for roads with high traffic due to the major safety risks and quality requirements correlated with the pavements usually used on that types of roads. In this context further studies are required to be performed in order to continuously improve the pavements which have unconventional materials incorporated into the mixes from the physical and mechanical point of view.

## References

Al-Qadi, I. L., Sayed, T., Alnuaimi, N., and Masad, E. Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling. CRC Press, 2008.

Al-Rousan, T., Asi, I., Al-Hattamleh, O., and Al-Qabla, H. Performance of Asphalt Mixes Containing RAP. Jordan Journal of Civil Engineering, 2 (3), (pp. 218-227), 2008.

Anochie-Boateng, J. K., and Tutumluer, E. Sustainable Use of Oil Sands for Geotechnical Construction and Road Building. Journal of ASTM International, (p. 33), 2012.

Condurat, M., and Patterson, J. Welsh and Romanian Policies for transition towards low carbon mobility. Proceedings of the International Conference "Smart Energy Regions", (pp. 59-70). Cardiff, U.K, 2016.

Curran, M. A. Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products. John Wiley & Sons, 2012. https://doi.org/10.1002/9781118528372

EPA, Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices U.S. Environmental Protection Agency, 2009.

Office of Solid Waste and Emergency Response

FHWA. Asphalt Pavement Recycling with Reclaimed Asphalt Pavement (RAP). On line at: http://www.fhwa.dot.gov/pavement/recycling/rap/index.cfm. Federal Highway Administration. US Department of Transportation, 2011.

Florescu, E. Tehnologii speciale pentru reabilitarea drumurilor [Special Technologies for roads rehabilitation]. Ed. Matei-Teiu Botez Academic Society Iaşi, ISBN 978-973-8955-91-2, 2010.

Gwilliam, T. S. Economic Feasibility of Oil Sand Use in Asphalt Pavements. Utah Science Technology And Research Initiative (USTAR), 2010.

Ioniță, G., and Gugiuman, G. The usage of bituminous sands in road pavement asphalt mixtures composition. In International Scientific Journal Trans & MOTAUTO WORLD, year I, ISSUE 2/2016, ISSN 2367-8399, Scientific Technical Union of Mechanical Engineering, (pp. 40 – 42), 2016.

ISO. 14040, Life Cycle Assessment - Principles and Framework, 1997

Matasaru, T., Craus, I., and Dorobantu, S. Drumuri [Roads]. Bucuresti: Editura Tehnica Bucuresti, 1966.

Probstein, R. F., and Hicks, E. E. Synthetic fuels, oil shale and tar sands. (pp. 183-184). New York, Dover Publication Inc, 2006.

Speight, J. G. (2009). Coal, Oil Shale, Natural Bitumen, Heavy Oil and Peat - Volume 2 Coal, Oil Shale, Natural Bitumen, Heavy Oil and Peat - Volume 2. (p. 452). ISBN: 978-1-84826-018-4 (eBook) ISBN: 978-1-84826-468-7, 2009.

Treweek, J. Ecological Impact Assessment. Wiley-Blackwell, 2009.

TRL. Asphalt Pavement Embodied Carbon Tool. Transport Research Laboratory. online at http://www.sustainabilityofhighways.org.uk, 2014.

Vrtis, M. C. Creating a Performance-Based Asphalt Mix Design to Incorporate Uinta Basin Oil Sands. Master Thesis. Department of Civil and Environmental Engineering, The University of Utah, 2013.

## About the authors

**CONDURAT MIHAELA**

**PhD, Eng (Civil Engineering)**

Regional Directorate of Roads and Bridges Iasi (D.R.D.P. Iasi), Romanian National Company of Road Infrastructure Management (C.N.A.I.R. S.A Romania)

**Main research area**

Impact assessment of road transport system. Measures regarding the prevention and reduction of ecological impact associated with road transport infrastructure

**Address**

Gh. Asachi Street, No 19, Postal Code 700481, Iasi, Romania
Tel. +40 745 409 930
E-mail: conduratmihaela@yahoo.com

**GABRIELA IONITA**

**PhD Student, (Civil Engineering)**

Department of Transportation Infrastructure and Foundations, Faculty of Civil Engineering and Building Services, Gheorghe Asachi" Technical University of Iasi

**Main research area**

Bituminous sand usage in the road technology in Romania

**Address**

Dimitrie Mangeron Blvd., No 43, Iasi 700050, Romania
E-mail: gabrielaa.ionitaa@yahoo.com